Quantum phase transitions

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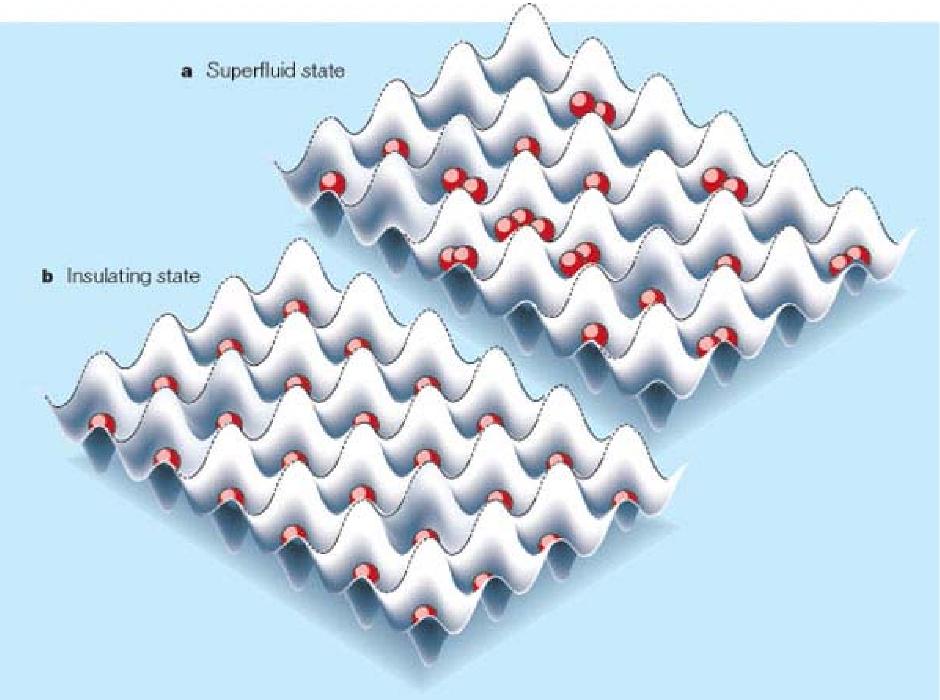
Our research uses the quantum principles of nature to understand the properties of a variety of materials important for their electrical and medical applications. For many materials (such as the high temperature superconductors), we have proposed that the quantum correlations between the electrons can be quantitatively described by a theory built on the proximity to a **quantum phase transition**. Unlike a familiar *thermal* phase transition (such as the melting of ice) driven by the increasing thermal agitation of the atoms, a *quantum* phase transition is driven by fluctuations induced by Heisenberg's uncertainty principle.



An illustrative example is our theory for the experiments of M. Greiner *et al*. (*Nature* **415**, 39 (2002)) on atoms trapped by lasers and driven through a quantum phase transition from an insulator (in which each atom is trapped in a potential minimum) to a superfluid (in which the atoms tunnel freely).

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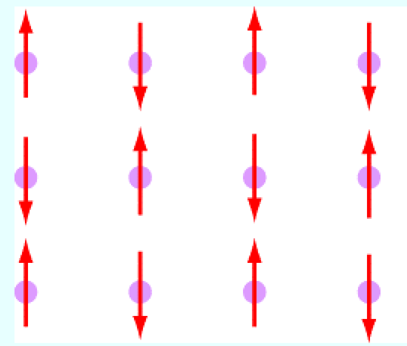
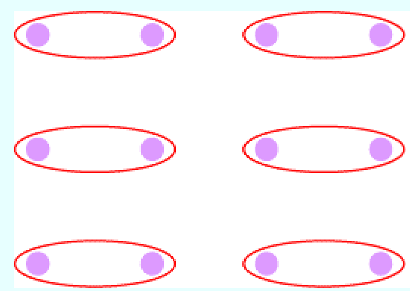
In the cuprate high temperature superconductors, the important degrees of freedom are electrons residing on Cu ions which form a square lattice. Each electron acts like a quantum bit (or *qubit*) with 2 states: with the electron spin oriented *up* or *down*. We have described properties of the cuprates using our theory for quantum phase transitions in models of qubits on the square lattice.

Young scientists trained: Lorenz Bartosch, Adam Durst, Kwon Park, Anatoli Polkovnikov, Stephen Powell, Matthias Vojta, Ying Zhang. A text book on quantum phase transitions was written, and numerous public lectures were presented: detailed and accessible information on these is available on the web site http://pantheon.yale.edu/~subir



A magnetic state with the qubits in a classical checkerboard arrangement.



$$= \frac{\left(|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle\right)}{\sqrt{2}}$$

Qubits `entangled' in a quantum superposition in valence bond pairs

Two phases of qubits on a square lattice which are separated by a quantum phase transition.